DSN Load Forecasting for Proposed Future NASA Mission Sets

W. A. Webb
Mission Design Section

This article describes a computer program, DSNLOAD, which provides load forecasting information given a DSN configuration and mission requirements for a set of proposed future NASA missions.

I. Introduction

As proposed future NASA interplanetary mission sets are considered, it is necessary to assess the load on the DSN given the individual tracking requirements for each of the proposed missions. A computer program, DSNLOAD, is described which provides DSN load forecasting information given a proposed future NASA mission set. In DSNLOAD, the DSN is analytically modeled so that spacecraft (S/C) tracking schedules are determined periodically throughout the future period of interest. These schedules are determined from the view periods or available tracking times for each mission on one sample day each month and reflect a typical or average tracking situation for the month. These typical tracking schedules are then transformed into data which shows the load or "how busy" each DSN station is "on the average" at different times of the day. The DSNLOAD model includes required pre- and postcalibration periods and station "overhead" such as maintenance or "down" time. Also included in the model is the option of "off-loading" some of the tracking load of a station which is overloaded onto another station.

DSNLOAD provides data which assists in identifying time periods in the future where the DSN may be overloaded and tracking requirements may not be satisfied for one or more missions. It also helps to identify tracking conflicts between missions, particularly at critical periods such as launch or encounter when intensive tracking is required. This information may influence the mission design or a decision to alter the capabilities of the DSN.

II. DSN Load Candidate Mission File

A flowchart of the procedure of selecting a possible future mission, determining a representative heliocentric orbit for the mission, generating view period schedules, and converting these schedules into Basic Loading Data for each mission at each station is shown in Fig. 1. The Basic Loading Data represents the percentage of available tracking time in different time slots during the monthly sample day. The Basic Loading Data for all possible missions is stored in a file called the Candidate Mission File for access by DSNLOAD. Given a proposed mission set, DSNLOAD reads the Basic Loading Data for the proposed missions from this file.

The missions which are included in a typical load forecasting study are either active or in-flight missions, missions which are funded as "projects" and scheduled for future launch, or missions which are being studied and considered as becoming possible "funded" projects in the future. Research is currently being carried out for possible interplanetary missions with launch dates throughout the rest of the century.

Early in the advanced studies process, a mission reference trajectory is generated. The reference trajectory is used to study and analyze mission characteristics. In this process, basic mission design parameters are determined such as launch date, arrival date, geocentric injection energy (C_3) required, and the direction of the geocentric injection vector. From these mission design parameters, a heliocentric geometric conic is determined which intersects the Earth at launch and the arrival planet (or other body such as a comet) at arrival for ballistic trajectories or a polynomial fit which approximates the trajectory for low-thrust trajectories. For planet orbiter missions, the heliocentric orbit of the planet is used during the orbital phase of the mission. For missions which are "in-flight," the actual launch and arrival date are used to determine the trajectory.

The reference trajectories are used to determine geocentric direction vectors as a function of time. From these direction vectors, the DSN station locations, and knowledge of the Earth's rotation, the view period schedules are generated. The view period schedules are generated for the 15th day of each month for the mission duration. For deep space missions, the configuration of view periods from station to station varies slowly from month to month and a sample rate of one day per month is adequate for generating future loading information.

The current DSNLOAD Candidate Mission File includes Basic Loading Data for 60 missions which are either currently in-flight or have been proposed for launch at some future date. Also included are Basic Loading Data for each of the nine planets, which may be used to study DSN loading for prospective planetary orbiter missions.

III. Tracking Schedule Model

The DSNLOAD tracking schedule model considers the tracking schedule to be represented by tracking passes which are of a maximum required length and centered within the view period or available tracking time for each mission. If view periods overlap for a station, no attempt is made to sequence tracking for the station or to distribute tracking over the entire available tracking period.

The assumption that each tracking pass is centered in the middle of the view period provides a model which is computationally simple, is easily understood by upper level technical management which use the results in decision making, and which identifies potential tracking requirement conflicts or time periods where view periods for two or more missions overlap and tracking requirements cannot be satisfied. In a sense, the model provides a "reasonable" upper bound on the potential overload for a given tracking situation. Since in actual tracking, overlap is not possible (a station cannot normally track more than one spacecraft at a time), a sequencing scheme is worked out as a result of human decision-making reflecting compromises between conflicting requirements by representatives of the active missions at that time. The DSNLOAD tracking schedule model provides a reasonable upper bound on maximum loading or a "worst case" situation. This serves to identify time periods and times during the day when there may be potential overloading problems and tracking requirements cannot be met. Monthly view period charts which are printed by the program throughout the period of interest assist in determining and understanding where potential conflicts may occur.

The basic assumptions of the DSNLOAD tracking schedule model are now stated as follows:

(1) The view period schedule for each mission for each month is represented by the schedule for the 24-hr day on the 15th of the month.

(2) The tracking pass for a given mission at a station is assumed to be of a required maximum length and centered in the middle of the view period.

(3) The tracking requirements (i.e., number of tracking passes/month required for a mission) are handled by weighting multipliers.

(4) For each tracking pass, pre- and postcalibration periods are added which are represented as an extension, at the beginning and end, of the tracking pass.

(5) The loading due to station overhead (maintenance or "down" time) is added after the tracking schedule for the mission set has been determined.

The first assumption is based on the premise that for interplanetary missions the view period configuration at each station varies slowly from day to day and that a sample rate of once per month is adequate for generating future loading information. Monthly loading data is then averaged into quarterly data to provide an overall picture of the loading situation over the time period of interest, usually 10 or more years in a typical loading study.

The tracking requirements are provided by representatives of each mission and are specified as the number of tracking passes desired during each month at each station. For each mission, the average loading contribution is determined by breaking up the sample day (the 15th of the month) into six 4-hour time slots, computing the tracking load in each time slot and then multiplying each of these loading percentages by a weighting multiplier which reflects the tracking requirements.

Load contributions for each mission and each of the six 4-hour time slots are computed in the same manner and the load summed over all missions to get the total average load contribution at the station for the month due to spacecraft tracking. The "overhead" is then added for the station to get the total load for the month. Monthly loading data is then averaged into quarterly data and printed by the program in the form of "loading matrices."

A schematic for computing the average load for one month, for a set of missions at one station, is presented in Fig. 2. The load contribution for each mission is computed at each station and the load is summed over all missions to get the total load at each station. Maintenance or station "overhead" time is then added to obtain the total load contribution for the mission set at each station.

The station maintenance model is designed to reflect the load contribution which is due to the necessary time when the station is not actually tracking, but is being repaired or maintained. The DSN maintenance shifts are typically 4 to 8 hours long and performed on as regular a basis as possible at times when a station is least busy with spacecraft tracking. The basic strategy of the DSNLOAD maintenance algorithm is to assign the maintenance load for each station, each month, to the time slots in ascending order of load percentage and in proportion to the relative amount of tracking time available in each time slot. The maintenance load is almost always distributed over at least two time slots. If there is not enough available time for the required maintenance load, the time slots with available time are filled to 100% and the remaining maintenance load distributed evenly throughout the day. The maintenance time is input into DSNLOAD as the average number of hours of maintenance time required per month for each station. The maintenance load in hours/month is converted to loading percentage in a 4-hour time slot by the program.

IV. Calculation of DSN Loading Matrices

After the total average load contribution, in each time slot, is determined at each station for each month of the period of interest, the monthly loading data are averaged into loading matrices which show the average quarterly loading for a year. The loading matrices give an "overall picture" of the loading situation, as a function of time, for each quarter at each station.

A loading matrix is a 6×4 array of numbers,

$$Q = \begin{bmatrix} q_{11} & q_{12} & q_{13} & q_{14} \\ q_{21} & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ q_{61} & \cdot & \cdot & q_{64} \end{bmatrix}$$

where each q_{kl} is the average percentage of time that the station is busy, due to tracking and overhead, for the kth 4-hour time slot and the 1th quarter of the year. An element, q_{kl}, of the loading matrix whose value is greater than 100%, indicates that the station is overloaded "on the average" for the kth time slot and 1th quarter of that year.

In assessing loading, two subnets of the DSN are usually considered, each consisting of three stations located at Goldstone, California, Australia and Spain. The subnets are designated the "34-meter net" and the "64-meter net." In terms of loading assessment, the 64-meter subnet generally has more capability than the 34-meter subnet so that an overload on the 34-meter subnet may be "off-loaded" onto the 64-meter subnet but not vice-versa.

The DSNLOAD off-loading model considers the Q matrices for stations in the same location of each subnet on an element by element basis. Let q_{kl}^{34} represent the loading percentage for the kth time slot and 1th quarter of the year for the 34-meter station and q_{kl}^{64} represent the loading percentage for the kth time slot and 1th quarter of the year for the 64-meter station. The assumptions of the DSNLOAD off-loading model are as follows:

(1) If $q_{kl}^{34} \leqslant 100$, no off-loading is necessary.

(2) If $q_{kl}^{34} > 100$ and $q_{kl}^{64} \geqslant 100$, off-loading from the 34-meter station to the 64-meter station is not permitted since the 64-meter station is already overloaded.

(3) If $q_{kl}^{34} > 100$ and $q_{kl}^{64} < 100$ then,

  (a) If $q_{kl}^{34} + q_{kl}^{64} \leqslant 200$, split the load equally between the 34-meter station and the 64-meter station.

  (b) If $q_{kl}^{34} + q_{kl}^{64} > 200$, load the 64-meter station up to 100% and assign the remaining load to the 34-meter station. (Note, in this case the 34-meter station is still overloaded for this time slot and quarter.)

In the DSNLOAD output, for a typical loading study, the loading matrices for the three stations for each subnet are computed and printed, as well as the "off-loaded" loading matrix for each station.

Two other types of loading matrices are computed and printed for each subnet for each year which summarize the results over each subnet: a Maximum Loading Matrix and an Average Loading Matrix. A Maximum Loading Matrix is a 6 X 4 array of numbers,

$$Q^m = \begin{bmatrix} q^m_{11} & q^m_{12} & q^m_{13} & q^m_{14} \\ & & & \cdot \\ q^m_{21} & & & \cdot \\ \cdot & & & \cdot \\ q^m_{61} & \cdot & \cdot & q^m_{64} \end{bmatrix},$$

where each q^m_{kl} is the maximum percentage of time that the subnet is busy, due to tracking and overhead, or the maximum value of q_{kl} taken over the three stations of the subnet for the kth time slot for the lth quarter of the year. The Maximum Loading Matrix shows peak loading on the subnet and identifies time periods when the DSN as a whole is overloaded.

An Average Loading Matrix is a 6 X 4 array of numbers,

$$Q^a = \begin{bmatrix} q^a_{11} & q^a_{12} & q^a_{13} & q^a_{14} \\ & & & \cdot \\ q^a_{21} & & & \cdot \\ \cdot & & & \cdot \\ q^a_{61} & \cdot & \cdot & q^a_{64} \end{bmatrix},$$

where each q^a_{kl} is the average percentage of time that the subnet is busy, or the average value of q_{kl} taken over the three stations of the subnet for the kth time slot for the lth quarter of the year. The Average Loading Matrix provides an "overall picture" of what the loading situation on the DSN will be for each quarter of the year.

For each type of loading matrix, the quarterly average is computed and printed. This is the average of the six elements of each column of the loading matrices. This provides an "overall picture" of what the load is for each quarter and allows comparison of the average load between quarters.

V. Further Development

The DSNLOAD program, using the view period tracking model described in this paper, is currently operational at JPL and is used to assess future DSN capability and mission feasibility by JPL and NASA management. This data provides a reasonable "upper bound" on what future loading might be and assists in identifying time periods where DSN overloads may occur. Detailed examination of view period charts printed out by DSNLOAD provides further insight into potential overloading problems.

A second DSN tracking model, which is now being developed by the author, will attempt to determine an optimal or "ideal" tracking schedule for a given mission set. This optimal tracking model will utilize mathematical programming techniques to periodically determine a tracking schedule which is optimal in the sense of maximizing the tracking capability of the DSN with respect to the tracking requirements of the mission. In actual experience, tracking schedules are determined by human decision making, reflecting compromises of conflicting requirements by representatives of the missions and are not necessarily optimal by any "predictable" performance measure. So it is intended that the optimal tracking model provide a "lower bound" on the predicted tracking situation and that the two models provide "best" and "worst" case limits on what the actual loading situation might be. This lower bound information, along with current DSNLOAD results, will advance further the technology of using a computer model of the DSN to forecast future DSN loading.

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References

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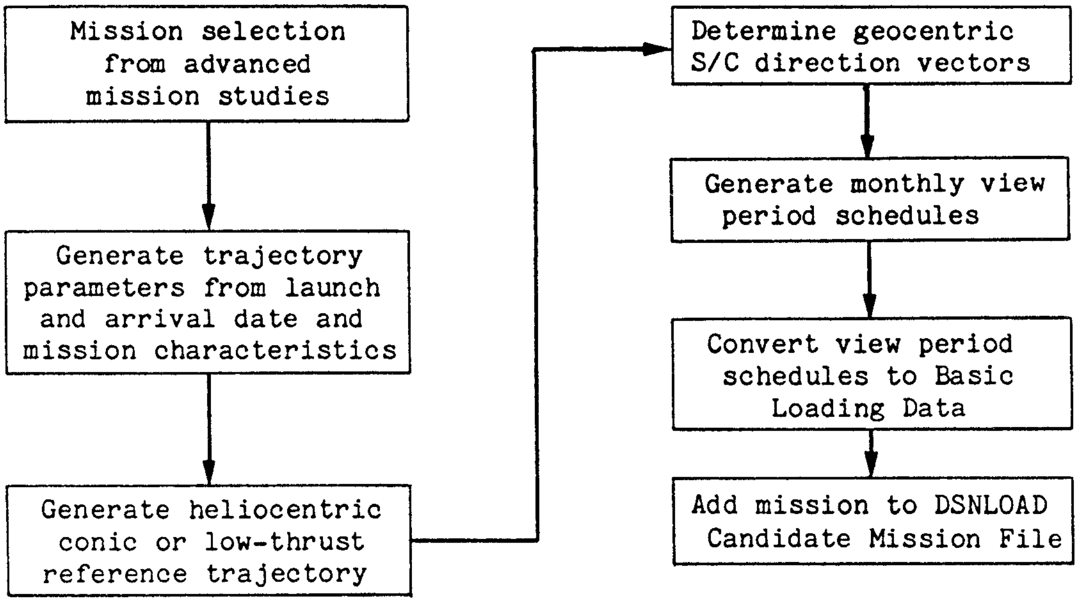

Fig. 1. Procedure for determining Basic Loading Data for a proposed future mission

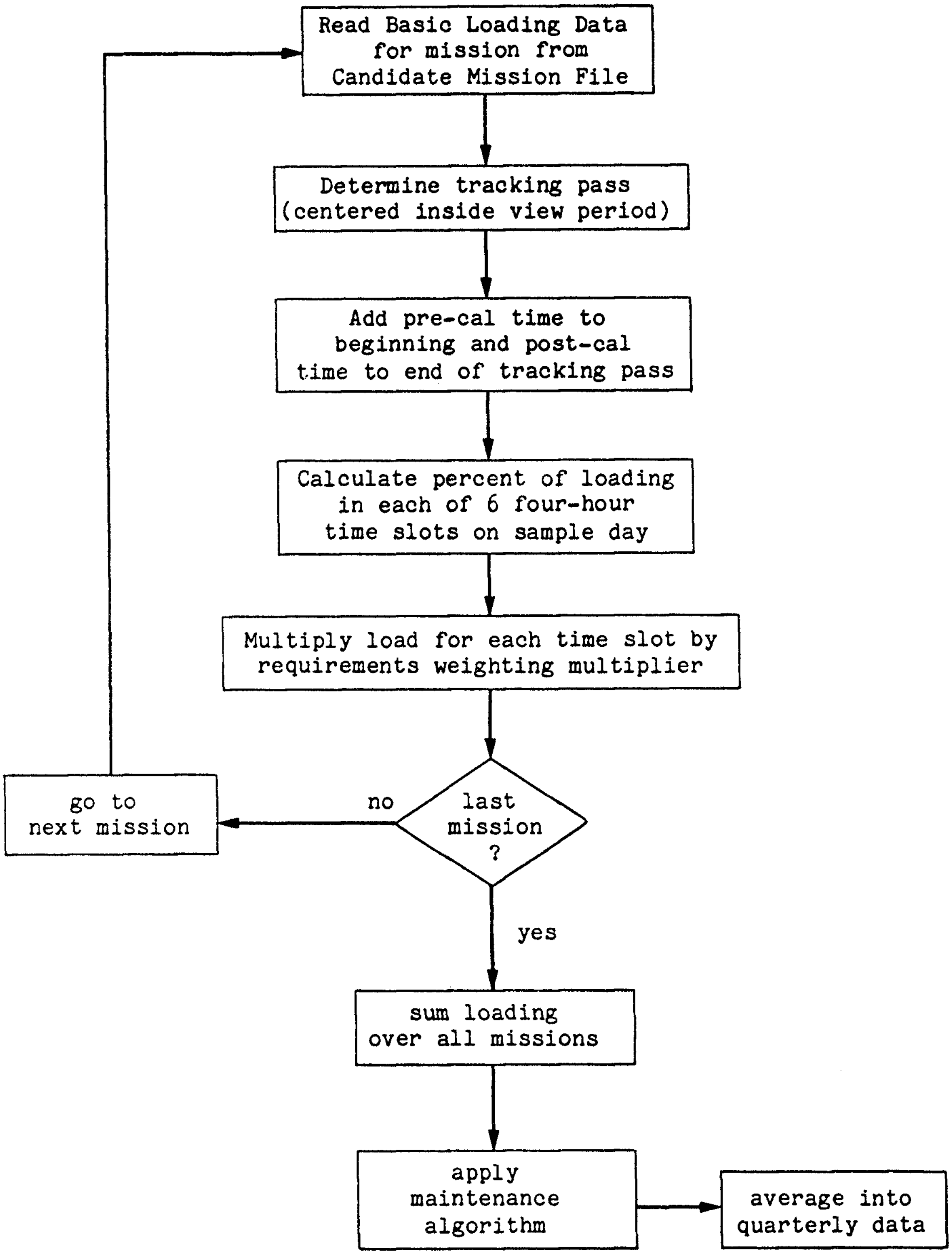

Fig. 2. Procedure for computing the average load for a month, at one station, for a set of missions